Nevada Division of Environmental Protection

Bureau of Water Pollution Control

NUTRIENT MANAGEMENT for REUSE & BIOSOLIDS SITES

WTS-1C

December 2012 (1st publication)

I. Introduction:

This guidance document provides a general overview of wastewater nutrient reduction and management strategies that can be implemented at reclaimed water reuse sites and ranches fertilized with municipal biosolids. The reduction of nutrients in treated effluent discharged to groundwater, surface water or an irrigation site is now considered as important in regulation as the traditional role of a treatment works in reducing organic matter and pathogens to levels considered safe for public and environmental health protection. Figure 1 below indicates the nitrogen cycle for municipal wastewater denitrification (Note: presently, NDEP permits reclaimed water only for irrigation of landscaping or forage crops). Table 1 on the next page illustrates typical influent constituents observed in municipal treatment works (POTWs), including the nutrients Total Nitrogen (TN) and Phosphorus (P).

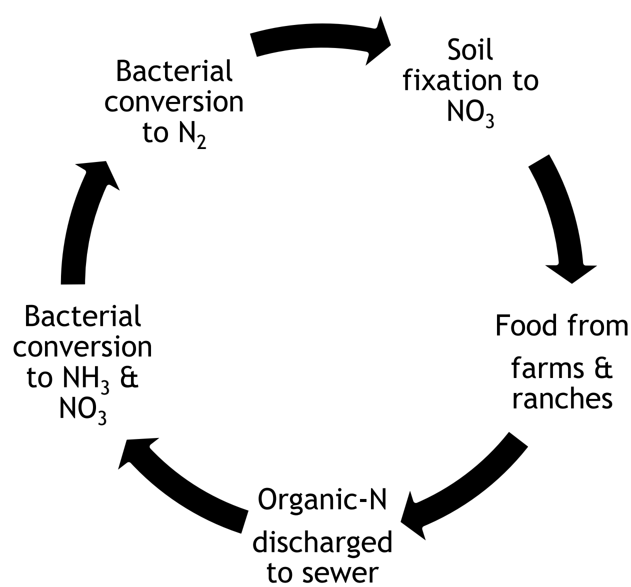

Fig. 1 – Wastewater Nitrogen Cycle

Table 1 – Domestic Wastewater Constituents

Facility	Flow (Gals/day)	BOD_5 (mg/l)	TSS (mg/l)	FOG (mg/l)	pH (S.U.)	TN (mg/l)	P (mg/l)
POTW (Residential)	75-120	180-260	180-260	50-100	6-9	30-50	6-10

II. Denitrification Process:

Residential and commercial connections to wastewater collection systems discharge organic nitrogen in wastewater including urea (urine), fecal matter, kitchen food scraps and cleaning detergents, which contain ammonia (ammonium) cleaning compounds. Nitrogen is also discharged to the environment from non-point source runoff and leaching from feedlots, farms and fertilized landscape including lawns. Once discharged into the sewer, bacteria begin hydrolyzing (decomposing) organic nitrogen into ammonia (ammonium) nitrogen in a process called ammonification. Discharge of treated effluent must consider the management of residual nitrogen to appropriate levels to minimize impact to receiving waters. Excess nitrate levels in potable water supplies can lead to a life-threatening condition in humans called Methemoglobinemia or “blue baby syndrome”. In surface water, excess nitrogen contributes to algae blooms, which can kill fish and cause odorous conditions. Biological reduction of nitrogen is known as denitrification requiring the reduction of TN ≤ 10 mg/l for potable supply protection. Denitrification occurs in three steps. The first two steps proceeds aerobically at dissolved oxygen (D.O.) levels ≥ 2.0 mg/l and is called nitrification. First, *Nitrosomonas* bacteria convert ammonia (NH_3) into nitrite (NO_2). Then, *Nitrobacteria* convert the nitrite into nitrate (NO_3). The third step is provided in an anoxic environment with D.O. levels < 0.5 mg/l. *Pseudomonas* bacteria convert the nitrate into gaseous nitrogen (N_2), which is discharged to the atmosphere composed mainly of nitrogen (78%) and oxygen (21%) gases. *Pseudomonas* requires a carbon source present in the influent or later added as a supplement in a post-anoxic reactor (e.g. methanol). The nitrogen cycle is renewed when nitrogen-fixing bacteria (*Rhizobia*) growing on plant legume roots (e.g. alfalfa) convert the atmospheric nitrogen into soil ammonia. Further conversion to soil nitrate by nitrogen fixing bacteria provide the nitrogen necessary for crop growth. Figure 2 on the next page indicates the process flow diagram for a generic denitrifying treatment works incorporating anoxic and aerobic selector zones. In this hypothetical treatment works, the carbon is sourced from the influent sewage.

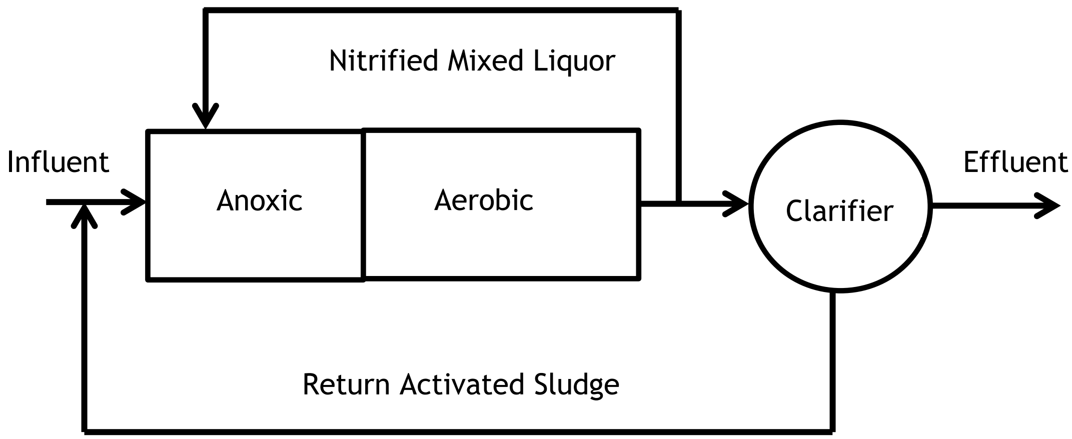

Fig. 2 – Activated Sludge Denitrification

III. Phosphorus Removal Process:

In addition to urea and fecal matter, phosphate (PO_4) is also contributed from cleaning products including automatic dishwasher detergents. In the 1990s, U.S. manufacturers discontinued adding phosphate builders to laundry detergents, while local jurisdictions are now assessing limiting phosphorus in dishwashing detergents. Phosphorus can be the limiting factor in an aquatic environment causing an algae bloom when assimilated with nitrogen by algae, cyanobacteria and other green plants. Cyanobacteria (blue-green algae) blooms can be toxic to humans or livestock if the planktonic bloom releases phytotoxins. Seasonal phosphorus reduction, typically required in summer months, is now practiced year-round on a voluntary basis for POTWs discharging to the Las Vegas Wash. Typical phosphorus limits in Nevada are ≤ 2.0 mg/l depending on the receiving stream's water quality standard. Phosphorus removal is either chemical or in conjunction with a biological process. Chemical precipitation of phosphates uses lime or a metallic salt (aluminum or iron) as the coagulant. Biological removal of orthophosphate occurs in anaerobic and aerobic selector zone environments. The polyphosphate-accumulating organisms (PAOs) are removed as a waste activated sludge and dewatered. Additional chemical precipitation may be required if the phosphate is released during the solids dewatering and builds up in the filtrate (centrate). Phosphorus can be recycled back to the land as biosolids or precipitated from the filtrate and recovered in fertilizer form such as the precipitate struvite (magnesium ammonium phosphate). Figure 3 on the next page indicates a process flow diagram for a generic chemical treatment system to remove (precipitate) phosphorus in the secondary effluent of a municipal treatment works.

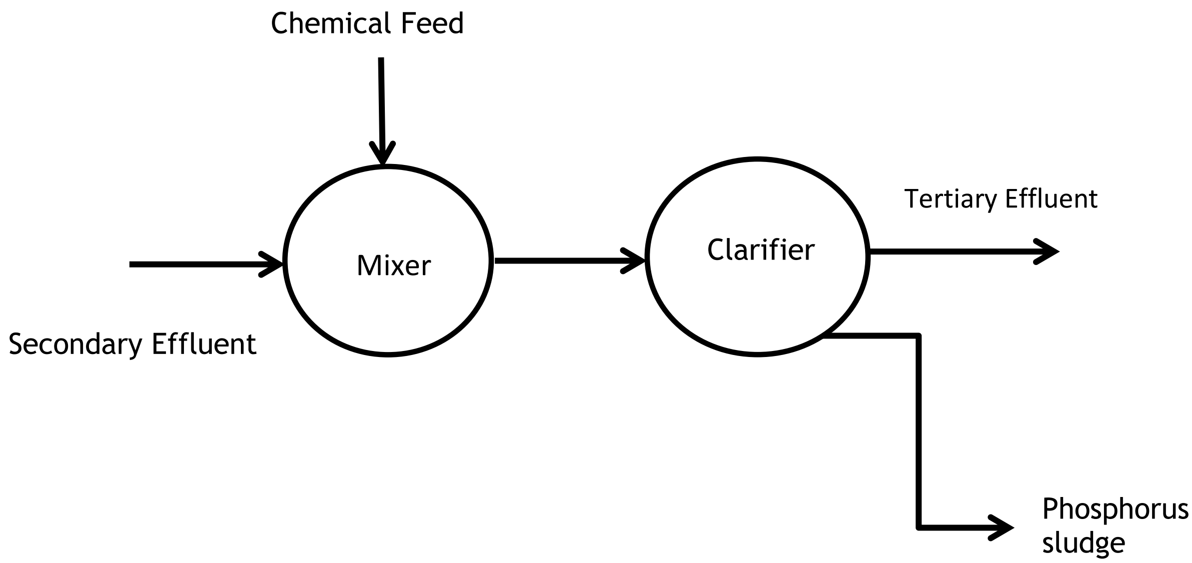

Fig. 3 – Chemical Phosphorus Precipitation

IV. Biosolids Application:

Biosolids are dewatered sewage sludge solids processed to meet Class A or B fecal coliform levels. Digested biosolids meeting Class B levels ($< 2\times10^6$ Most Probable Number/gram) are suitable for forage crop (animal feed) production at publicly restricted land application sites. Nitrogen application is limited to the crop's agronomic requirement to avoid leaching. Additional treatment by composting, heating or chemical addition can be used to meet Class A level (< 1,000 Most Probable Number/gram). Public distribution of Class A biosolids may require additional testing of *Salmonella* bacteria, helminthes ova (parasitic worms) or enteric (intestinal) viruses. Biosolids blended and composted with green waste (e.g. raked leaves, lawn clippings, chipped brush) produces a rich soil (humus) amendment. The organic nitrogen content is stabilized, which is then released slowly at the plant's uptake need. Table 2 on the next page provides sample nitrogen uptake rates for forage crops. The recommended biosolids application rate is determined with periodic testing of the biosolids nitrogen availability.

Table 2 – Forage Crop Uptake Rates

EXAMPLE AGRONOMIC RATES	
Forage Crop	**Nitrogen Uptake (lbs. N/ton crop)**
Alfalfa	60
Clover	50
Grass Hay	40
Wheat (silage)	40
Triticale	40
Barley (silage)	35
Sudan or Crested Wheat	33

V. Turf Management:

Turf grass requires nitrogen availability (nitrate/ammonia nitrogen) supplied either in the soil, water supply or supplemental fertilizer. Plants incorporate nitrogen from nitrate (primary) and ammonia (secondary) forms. Water-soluble nitrogen forms such as ammonium nitrate are incorporated quickly into the plant leaf structure, but the application rate must be managed to minimize leaf burn. Reclaimed water meeting a Category A (Total Coliform) or B (Fecal Coliform) disinfection level of 2.2 / 23 (Most Probable Number) is suitable for sprinkler application of landscaping with zero buffer zone. Reclaimed water with higher coliform levels is allowed for drip or flood application or by spray irrigation with specified buffer zones to restrict public access. Spray irrigation is mainly during night time hours except when managed in daytime hours with close employee supervision to ensure that public access is restricted from all areas being irrigated with reclaimed water. Turf irrigated with reclaimed water includes fescue, rye, bent, Kentucky and Bermuda grasses. Specific nitrogen requirements are to be developed by a qualified professional (e.g. agronomist, certified golf course superintendent or licensed engineer) and specified in the Effluent Management Plan (EMP) reviewed and approved by NDEP. Nitrogen application rates in Nevada can vary by location, turf and intended use but generally range 3 to 10 lbs. N/1,000 ft^2-yr. (130 to 435 lbs. N/acre-yr.). In general, higher application rates of nitrogen require additional irrigation, mowing and landscape upkeep. Reuse sites irrigating with reclaimed water TN levels > 10 mg/l are required to report an annual nitrogen budget. This budget must account for all sources of nitrogen applied (reclaimed water and fertilizer), and the nitrogen application rate is to be maintained within the permit limitations and approved EMP specification. Your reclaimed water provider will have lab data analyzed at a NDEP-certified lab to determine the reclaimed water nitrogen levels. Reclaimed water nitrogen levels may vary seasonally since denitrifying bacteria efficiency is reduced in some treatment works in colder months. Assuming no nitrogen loss factor "f", the following formula provides an estimation of the nitrogen supplied in reclaimed water.

$$\text{lbs. N (Reclaimed water)} = (\text{Million Gallons Applied}) \times (\text{Total-Nitrogen, mg/l}) \times 8.34$$

The nitrogen budget may also include a loss factor "f" to account for the fraction of nitrogen lost to soil denitrification and ammonia volatilization. The amount of nitrogen lost depends on effluent volatility (ammonia) and microbial activity in the soil. For arid climates, such as Nevada, the value typically used for the "f" term is up to 0.2. For further information, refer to the Division's guidance documents WTS-1A or WTS-1B on the NDEP-BWPC website (click on the link to "Technical Publications & Fact Sheets").

VI. Supplemental Fertilization:

The EMP may recommend supplemental fertilization if nitrogen is limited in the reclaimed water supply. In Nevada, supplemental nitrogen may be applied once annually, bi-annually, quarterly or up to a monthly frequency based on the facility's O&M budget, location and type of turf. Application rates generally range ¼ to 1 lb. N/1,000 ft^2 per fertilizer event (10 to 43.5 lbs. N/acre per fertilizer event) to limit leaf burn. Proprietary fertilizers also include "slow-release" formulations designed to prevent leaf burn by releasing nitrogen compounds slowly in accordance with the plant's desired growth rate. Fertilizer manufacturers provide their nitrogen availability on a percentage by weight basis in the "Guaranteed Analysis" formulation printed on the packaging content. The following equation can be used to determine the nitrogen added from a turf spreader broadcasting a solid fertilizer product.

$$\text{lbs. N (Fertilizer)} = (\text{lbs. Fertilizer}) \times (\text{\% by Weight Total-Nitrogen})$$

VII. Conservation:

For environmental protection and/or permit limit compliance, the operator of a treatment works, reuse facility or biosolids application site may have to implement a nutrient reduction plan to limit the discharge or use of either nitrogen and/or phosphorus. The following provides examples of how this can be accomplished.

a. Sewer Ordinance: Overloaded POTWs can adopt local ordinances restricting the discharge of food wastes into the collection system, e.g. limit on food waste grinders. Kitchen food scraps and green wastes can instead be collected and recycled at municipal composting facilities.

b. POTWs: If plant capacity allows, aeration compartments can be converted to anoxic or anaerobic selector zones to remove nitrogen and phosphorus biologically. Chemical coagulants can be dosed for precipitating phosphorus removed in a clarifier or filter.

c. Wastewater Ponds: Aerating wastewater ponds strips (volatizes) ammonia. Final effluent from a polishing pond or reservoir is recycled to the primary pond to promote partial denitrification. Leaking ponds are upgraded with impermeable liners (HDPE). Accumulated sludge in ponds is removed when sludge levels increase > 20% of design depth.

d. Storage Ponds: Water clarity is improved in irrigation ponds with supplemental aeration to strip off ammonia and carbon dioxide gases to reduce algae growth.

e. Turf: Water and nitrogen demand of turf is reduced with replacement (xeriscaping) and mulching of the cuttings. In alkaline soil, nitrogen use if more efficient with operation of a pond sulfur burner or soil amendment such as gypsum.

f. Weeds: At the end of each growing season, aquatic vegetation and other weeds are removed from ponds, rapid infiltration basins (RIBs) and land areas contacted with reclaimed water to cycle out nitrogen. The O&M program should include an annual program of disking, scarification, cutting or managed burning in the RIBs.

g. Wetlands: Constructed wetlands serve as polishing basins improving reclaimed water quality through nutrient uptake and biological filtration. Similar to RIB O&M, surplus vegetation should be harvested annually.

h. Crops: Forage legumes (e.g. alfalfa, clover) improve soil quality by nitrogen fixing of atmospheric nitrogen. Nitrogen fixing may provide all of the legume crop's nitrogen demand or reduced fertilizer demand when rotated with non-legume forage crops.

VIII. Groundwater:

Monitoring wells and/or piezometers may be required at reuse sites on a case-by-case basis to monitor impact of leaching. Groundwater monitoring requirements are assessed by NDEP-BWPC on site criteria including background groundwater quality, depth to groundwater, reclaimed water quality and proximity to potable supply wells. To protect groundwater, the recommended "upper" value for the nitrogen level in the irrigation water that percolates past the turf root zone is 7 mg/l. A TN level ≥ 7 mg/l is the first "red flag" value in the monitoring wells. In no case, is the TN level to exceed 10 mg/l, which would then require a nitrogen reduction plan including strategies such as limiting fertilization, switching to a denitrified reclaimed water supply or limiting some irrigation zones to irrigate only with potable water. For further information on nitrogen percolation, refer to the Nitrogen Loading Limit Worksheets in either WTS-1A or WTS-1B.

IX. Budget:

Reuse sites irrigating with effluent TN levels > 10 mg/l are required to report an annual nitrogen budget. The reuse site will have to maintain data including volume of reclaimed water applied, reclaimed water nitrogen level, fertilizer added and acreage irrigated. Table 3 below provides an illustration of a fictitious 100-acre "Desert View" golf course irrigating with reclaimed water (TN = 12.5 mg/l, 0.5 MGD) and fertilized quarterly at a rate of ½ lb. N/1,000 ft^2. For illustration, the first month's application rate is provided. For brevity, nitrogen losses ("f" = 0) are assumed negligible.

Table 3 – Sample Nitrogen Budget

Desert View Golf Course - Annual Nitrogen Budget				
Month	TN in Reclaimed H_2O (mg/l)	Reclaimed H_2O Volume (Million Gallons)	lbs. N added (fertilizer)	Total lbs. N Applied
January	12.5	15	2,178	1,564 + 2,178
February	12.5	15	0	1,564
March	12.5	15	0	1,564
April	12.5	15	2,178	1,564 + 2,178
May	12.5	15	0	1,564
June	12.5	15	0	1,564
July	12.5	15	2,178	1,564 + 2,178
August	12.5	15	0	1,564
September	12.5	15	0	1,564
October	12.5	15	2,178	1,564 + 2,178
November	12.5	15	0	1,564
December	12.5	15	0	1,564
Total	**-**	**180**	**8,712**	**27,480**

Sample Calculations:

January: lbs. N (Reclaimed H_2O) = (Million Gallons Applied) × (Total-Nitrogen, mg/l) × 8.34

lbs. N (Reclaimed H_2O) = (15.0 MG) × (12.5 mg/l) × (8.34) = 1,564 lbs. N

lbs. N (Fertilizer) = (lbs. Fertilizer/1,000 ft^2) × (43,560 ft^2/acre) × (# of Acres)

lbs. N (Fertilizer) = (0.5/1,000) × (43,560 ft^2/acre) × (100 acres) = 2,178 lbs. N

Annual: lbs. N/acre = (Annual lbs. N applied, all sources) / (# of Acres)

lbs. N/acre = (27,480 lbs. N-yr.) / (100 acres) = 275 lbs. N/acre-yr.

Summary: The above facility's annual Nitrogen application rate of 275 lbs. N/acre-yr. would need to be compared with the allowable nitrogen application rate specified in the permit and approved EMP. If a site is over-fertilized, it would need to contact NDEP to discuss a compliance plan including possible nitrogen reduction.

X. Miscellaneous Formulae:

a. Million Gallons = (Million Gallons/day) × (days/month)

b. Acre Feet (volume) = (Million Gallons) × 0.326

c. Acreage (surface area) = (ft^2) / 43,560

d. Total Nitrogen (TN) analysis equals the summation of nitrate-nitrogen (NO_3-N), nitrite-nitrogen (NO_2-N), ammonia-nitrogen (NH_3-N), ammonium-nitrogen (NH_4-N) and organic nitrogen (Organic-N) species.

e. Total Kjeldahl Nitrogen (TKN) analysis equals the summation of ammonia-nitrogen (NH_3-N), ammonium-nitrogen (NH_4-N) and organic nitrogen (Organic-N) species.

XI. Acronyms:

AF	Acre Foot (Acre Feet)
BOD_5	5-Day Biochemical Oxygen Demand
BWPC	Bureau of Water Pollution Control
Division	Nevada Division of Environmental Protection
FOG	Fats, Oils & Grease
MG	Million Gallons
MGD	Million Gallons per Day
mg/l	Milligrams per liter
N	Nitrogen
N_2	Nitrogen Gas
NO_2	Nitrite
NO_3	Nitrate
NH_3	Ammonia
NH_4	Ammonium
pH	Potential of Hydrogen
P	Phosphorus
POTW	Publicly Owned Treatment Works
S.U.	Standard Units (pH)
TKN	Total Kjeldahl Nitrogen
TN	Total Nitrogen
TSS	Total Suspended Solids
WTS	Water Technical Sheet

XII. References:

i. *Nitrification & Denitrification*, The Water Planet Company.

ii. *Nitrate and Drinking Water from Private Wells*, Centers for Disease Control and Prevention.

iii. *Crop Nutrient Tool,* United States Dept. of Agriculture.

iv. *Nutrient Uptake and Removal by Field Crops*, Canadian Fertilizer Institute (1998).

v. *Phosphorus Removal from Wastewater*, Lenntech Water Treatment Solutions.

vi. *Turfgrass Fertilization*, University of Illinois Turfgrass Program (1998).

vii. *Chapter 445A – Water Controls*, Nevada Administrative Code.